AN ELECTRICAL METHOD OF SAMPLING EARTHWORM POPULATIONS

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An electrical method of sampling earthworm populations is described for use where chemical expellants are unsuitable. An alternating current of 2–4 amperes from the mains supply is regulated by a transformer and a potentiometer, and is discharged from a water-cooled electrode. The electrode is pushed into the ground to a depth of 18 inches and the current is discharged for 40 minutes. A set of seven concentric metal rings mark out the area around the electrode into bands three inches wide from each of which expelled earthworms are collected separately. Populations of mature and immature earthworms of each species are estimated separately, taking in each case, as the basis of the estimate, the three-inch ring in which most specimens per unit area are collected. The accuracy of the method is discussed and it is suggested that a more accurate representation of the species composition of earthworm populations is obtained with the electrical method than with the permanganate method.

Earthworm populations were estimated by EVANS and GUILD (1947) on the basis of the numbers of earthworms expelled from the soil in sample areas treated with potassium permanganate solution. This method is, however, unsuitable for experimental sites such as manurial or insecticidal test plots where the introduction of chemical expellants to the soil would disturb the experiment and on such sites sampling by digging may also be precluded. For sampling this type of site methods have been developed which use an electrical stimulus to bring the earthworms up to the soil surface.

American anglers have long been familiar with an electrical device (WALTON, 1933) consisting of a simple metal probe, which is pushed into the ground, and a cable and plug for connexion with a domestic electric power supply. After the current has been switched on for some minutes, earthworms come up around the probe and are collected for fishing bait. Johnstone-Wallace (*in litt.*) used a modification of this apparatus for sampling the earthworm populations of experimental grass plots at Cornell University and DOEKSEN (1950) also expelled earthworms electrically using three electrodes and a three-phase generator. Unfortunately, the accuracy of population estimates based on these methods cannot be defined

as the volume of soil affected and the proportion of earthworms expelled are quite unknown. An attempt was made therefore to develop a more accurate electrical sampling technique.

THE REACTIONS OF EARTHWORMS TO ELECTRICAL STIMULATION

In preliminary experiments it was found that a current output from an electrode in the soil of not less than half an ampere was necessary for earthworms to be brought to the soil surface. When smaller currents were discharged into the ground from an induction coil at potentials up to 50,000 volts the earthworms remained unaffected.

Alternating and direct currents were compared in a field trial and direct current was found to be comparatively ineffective in expelling earthworms. From four sites which were subjected first to a period of direct current and then to an equal period of alternating current, 72 worms were collected after the alternating current discharge and only 10 after the direct current discharge.

A type of alternating current can be produced by a pulsator from a direct current supply such as a car battery or dry cell, but this would yield a low amperage at a high voltage, a combination which the induction coil experiment showed to be useless for expelling earthworms.

The shocking potency of a range of frequencies was investigated by comparing the contraction of mature specimens of *Lumbricus terrestris* shocked at a constant amperage at frequencies from 50–3000 cycles. These frequencies were obtained by running an aeroplane alternator at various speeds and the earthworm contractions were recorded on a smoke drum. The shocking potency was found to vary inversely with the frequency and a current level of 30 microamperes which at 3000 cycles had almost no effect on the earthworms produced a state of rigid contraction when the frequency was reduced to 50 cycles. However, the contraction at 3000 cycles was equally intense if the current was increased by a few milliamperes.

Frequencies below 50 cycles were investigated by operating an electric bell in a circuit at various speeds but at this level no responses to change of frequency were detected. In developing a sampling technique there seemed, therefore, no advantage to be gained from using any frequency other than the 50 cycles of the mains power supply.

BEHAVIOUR OF ELECTRIC CURRENT IN SOIL AND ITS EFFECT ON DISTRIBUTION OF EARTHWORMS EXPELLED AROUND AN ELECTRODE

When a current of about 3 amperes was discharged into the soil, earthworms were expelled between about 3 inches and 3 feet from the electrode. Immediately adjacent to the electrode the earthworms were killed, while at a distance the current density was too low to be effective. In the intermediate zone the worms collected nearer the electrode were generally smaller than those collected further from it. This is explained by the current distribution in the soil and the depth distribution of the earthworms.

If the soil were a uniform medium and an electric current were supplied from a point source on the soil surface, zones of equal current density would form concentric hemispheres below the source. The actual distribution of current in the soil was plotted by measuring the current flow between various points around an electrode and the 'earth' line of a mains power point. The theoretical hemispheres are seen from *Figure 88* to be distorted to roughly flask-shaped zones by the elongate form of the electrode and the greater conductivity of the subsoil. The zone of current density which is optimal for stimulating earthworms to come to the soil surface may therefore extend laterally further into the subsoil than into the topsoil, so that deep burrowing earthworms would be expelled further away from the electrode than the surface-living

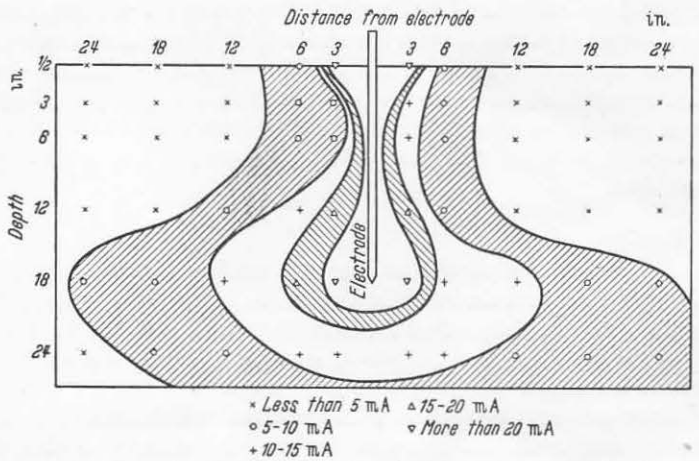

Figure 88—Vertical section of soil around an electrode showing current distribution.

species. The depth to which earthworms penetrated in a Rothamsted pasture field was found to be related approximately to their size, the three largest species *Lumbricus terrestris*, *Octolasium cyaneum* and *Allolobophora nocturna* penetrating to the subsoil, the smaller species *Eisenia rosea*, *Allolobophora caliginosa* and *Allolobophora chlorotica* living only in the topsoil, and the smallest species *Lumbricus castaneus* occupying only the surface layers. Furthermore, of the deep burrowing species only mature worms were found in the subsoil while immature specimens were confined to the topsoil. These two facts, the distribution of current density and the distribution of the earthworms, explained therefore the different distances from the electrode at which earthworms of different sizes were expelled.

STANDARDIZATION OF THE SAMPLING METHOD

With this information it was now possible to develop a standardized sampling method.

Sample area

Since the surface-living and deep-burrowing earthworms were being expelled from different areas it was decided to define the area sampled for mature and immature stages of each species separately. The area surrounding the electrode was marked out by a set of steel rings mounted on a frame into seven concentric bands, each three inches wide, between 6 and 27 inches from the electrode. The earthworms, as they appeared at the surface, were collected from each band separately into a set of seven correspondingly numbered jars and were then identified in the laboratory and recorded as mature or immature. The numbers collected were then converted to numbers per square foot and the populations of both age groups of each species were separately estimated, taking as a basis in each case the band which gave the highest number per square foot.

Current output

The electrodes employed in previous studies were simple, solid steel rods which were found to be unsuitable for continuous sampling since they heat rapidly when a current is passed through them and dry out the surrounding soil into an insulating band which reduces the current output.

A water-cooled electrode was constructed which overcame this difficulty and could be operated indefinitely without drying the soil. It comprised two copper tubes, one inside the other, which

connected to a water supply contained in two buckets provided with outlet taps (*Figure 89*). When the appropriate bucket was raised on a stand, water siphoned out down the inner tube of the electrode, up the outer tube and out into the second bucket. The positions of the buckets were then reversed and the water siphoned back again in the opposite direction, the time taken for each bucket to empty being about 12 minutes. The electrode had a steel tip mounted on a screw thread so that it could be detached and the tubes cleaned.

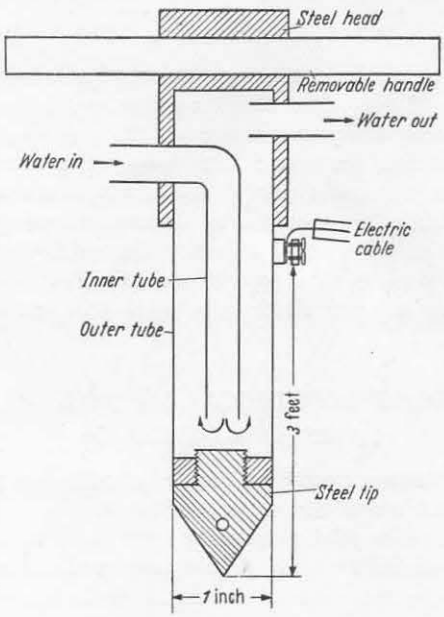

Figure 89—Water-cooled electrode.

In grassland soils at Rothamsted a current output of 2–4 amperes was required for sampling an area of convenient size. To discharge this current a potential of about 360 volts was required and this was obtained from the mains supply with a potentiometer in series with a transformer. The secondary winding of the transformer was connected at one end to the electrode and at the other end to the mains ' earth ' line. This arrangement allowed for regulation of the potentiometer to compensate for fluctuations in the mains voltage supply.

Sample depth

The depth at which the electrode could be used was determined by the penetrability of the soil. On grassland at Rothamsted 18 inches was the greatest depth to which it was possible to push the electrode with certainty and this was therefore adopted as the standard depth for sampling. The zone of optimum current density extends of course beyond the electrode and the measurement of current distribution in the soil suggested that it penetrated to about three feet, which was the maximum depth at which earthworms were found by digging.

Sample time

For the purpose of comparing the earthworm populations of field plots a collecting time of 40 minutes per sample was found adequate to yield a representative catch. During the first few minutes of sampling an active surface-dwelling species, *Lumbricus castaneus*, formed the main part of the catch, while the maximum number of *Allolobophora nocturna*, a deeper-burrowing species, was collected between 10 and 20 minutes after sampling had begun. Collecting for periods of longer than 40 minutes increased the total catch but did not materially alter its species composition (see Table 30).

COMPARISON OF ELECTRICAL METHOD WITH OTHER SAMPLING METHODS

Population estimates based on the electrical sampling method described are subject to two sources of error.

First, the limitation of the sampling time to 40 minutes results in an incomplete extraction of the earthworms and hence in an underestimation of the population density. Secondly, the empirical definition of the area sampled as the zone around the electrode in which most specimens were collected may lead to an over-estimate of the population density if the earthworms are unevenly distributed. If, for example, large numbers of *Lumbricus castaneus* are concentrated around an old dung-pat just beyond the zone receiving the optimum current density for sampling, then, although the proportion of specimens expelled from the three-inch band containing the dung-pat may be less than the proportion expelled from the optimum current zone, the actual number collected per unit area may be highest in the dung-pat zone.

Since the population estimate is based on the three-inch band with the highest number of expelled earthworms per square foot,

the band containing the dung-pat would, in this case, be selected as the sample area. Population estimates obtained by this method are not therefore based on strictly random sampling and tend to be biased by the selection of areas of high earthworm density. The net effect on the population estimate of this source of error and the error due to incomplete extraction was assessed approximately in the following way.

A grassland site was sampled electrically for 40 minutes, and after the expelled worms had been collected sampling was continued for a further 240 minutes after which no more earthworms came to the soil surface. The earthworm population density was then estimated by combining the estimates of the mature and immature populations of all the species present, each of which had been calculated on the basis of the three-inch band from which most specimens had been collected in the 280 minutes sampling. A nine-inch band around the electrode, 9–15 inches distant from it and 4·8 square feet in area, was then dug over to a depth of 18 inches and the remaining earthworms collected by hand. The earthworm population of the dug area was then calculated from the population density estimate and the actual number of earthworms present in it was obtained by adding the number expelled from it electrically and the number recovered by digging. This showed that the estimated number exceeded the observed number by 27 per cent of the estimate. However, the number of earthworms expelled electrically during the first 40 minutes sampling was only 40 per cent of the final number obtained after 280 minutes, so that had the sample time been limited to 40 minutes the net error would have been an under-estimate of the population of about 13 per cent.

Evans and Guild (1947) considered that the permanganate method of sampling also gave under-estimates of earthworm populations but since both the methods were tested by hand collecting from sites dug over after treatment, itself a method subject to unknown error, their absolute accuracy cannot be deduced from direct comparison. However, a comparison of the two methods suggested that the samples obtained electrically were the more representative of the population in their species composition. Ten pairs of samples were taken in an undisturbed grass field, one set by the electrical method, sampling for 40 minutes, and one set by applying potassium permanganate solution at the rate given by Evans and Guild (*loc. cit.*) of $\frac{1}{4}$ ounce per gallon per 7·29 square feet to sample areas one yard square. After the expelled worms had been collected from the permanganate sites, a period of 20 minutes was allowed to elapse to ensure that all those which

would reach the soil surface had been recovered. The same quantity of solution was then applied to the same sites and a second collection was made. With the same interval of 20 minutes this was repeated until four applications had been made, each square yard site having then received a total of five gallons of solution. Of all the earthworms collected by permanganate treatment 59 per cent were obtained from the first application, 24 per cent from the second, 11 per cent from the third and 6 per cent from the fourth.

TABLE 30

Percentage composition of the earthworm fauna from 10 samples

	Permanganate standard application	*Permanganate 4 × standard application*	*Electricity, 40 minutes*	*Electricity, 200 minutes*
O. cyaneum	2	3	11	12
A. nocturna	41	29	15	15
A. caliginosa	24	27	23	25
A. chlorotica	7	11	9	14
E. rosea	6	11	22	22
L. terrestris	20	19	16	15
L. castaneus	0	0	2	1
No. examined	699	1187	119	399

Table 30 shows the species composition of these samples. The two collections obtained by permanganate treatment are similar in their percentage composition except for *A. nocturna*, of which the relative abundance appears to be over-estimated by the standard permanganate method. This is to be attributed perhaps to its well developed burrow system giving access to the solution, and to its violent activity when stimulated.

A relative under-estimate of *E. rosea* is suggested by the permanganate comparison, by the results from digging by Evans and Guild, and by comparison with the electrical samples. This is a relatively small and inactive species without wide burrows and it may be that the permanganate solution reaches it mainly by slow percolation through the soil.

Of the earthworms collected by the electrical method 30 per cent were obtained after the first 40 minutes from the three-inch bands on which the estimate was based. Nevertheless, the 40-minute catch and the 200-minute catch are strikingly similar in species composition and, taking into account the results of digging after sampling, it appears that the 40-minute electrical collection was representative of the population as a whole.

REFERENCES

Doeksen, J., 1950, An electrical method of sampling soil for earthworms. *Trans. 4th Int. Congr. Soil Sci.*, 129–131

Evans, A.C., and Guild, W. J. McL., 1947, Studies on the relationships between earthworms and soil fertility. I. Biological studies in the field. *Ann. appl. Biol.*, **34,** 307–330

Walton, W. R., 1933, The reaction of earthworms to alternating currents of electricity in the soil. *Proc. ent. Soc. Wash.*, **35,** 24–27

DISCUSSION

See discussion following Dr. Satchell's ecological paper (page 199).

Mr. J. A. Svendsen (Durham) also contributed the following notes on a comparison of sampling methods in earthworm population studies:

During September 1954 the wet sampling, or permanganate, technique of Evans and Guild (*loc. cit.*) was tested against a hand-sorting method involving the extraction of soil cores. The surface area of each permanganate sample was 1 m^2, that of the soil cores 1/35 of 1 m^2, and the depth of the soil cores was 20 cm. Five soil cores were removed from the adjacent but unaffected area of each of ten permanganate samples.

The ten m^2 sampled by the permanganate technique produced 350 worms; an average of 35 per m^2. The 1·43 m^2 sampled by the soil cores produced 639·5 worms; an average of 447·6 per m^2. Six species were involved: *Lumbricus terrestris* L., *Lumbricus castaneus* (Sav.), *Octolasium cyaneum* (Sav.), *Allolobophora terrestris* (Sav.), *Allolobophora caliginosa* (Sav.), and *Eisenia rosea* (Sav.).

The proportion of each species found by the two treatments was tested by analysis of variance and found to differ significantly in two cases. Relative to the proportions from the soil cores, the permanganate technique extracted more specimens of *Allolobophora terrestris* (56·58–33·47 per cent) and fewer *Eisenia rosea* (4·57–20·10 per cent) than expected.

It was concluded that the wet sampling or permanganate technique is unsatisfactory for comparative population studies of earthworms.*

* Mr. Svendsen's observations have subsequently been published in a somewhat fuller form—see Earthworm Population Studies: a Comparison of Sampling Methods. *Nature, Lond.*, **175**, 864 (1955)—Ed.